Standards for the diagnosis and management of complex regional pain syndrome: Results of a European Pain Federation task force

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Abstract: BACKGROUND Complex regional pain syndrome is a painful and disabling post-traumatic primary pain disorder. Acute and chronic complex regional pain syndrome (CRPS) are major clinical challenges. In Europe, progress is hampered by significant heterogeneity in clinical practice. We sought to establish standards for the diagnosis and management of CRPS. METHODS The European Pain Federation established a pan-European task force of experts in CRPS who followed a four-stage consensus challenge process to produce mandatory quality standards worded as grammatically imperative (must-do) statements. RESULTS We developed 17 standards in 8 areas of care. There are 2 standards in diagnosis, 1 in multidisciplinary care, 1 in assessment, 3 for care pathways, 1 in information and education, 4 in pain management, 3 in physical rehabilitation and 2 on distress management. The standards are presented and summarized, and their generation and consequences were discussed. Also presented are domains of practice for which no agreement on a standard could be reached. Areas of research needed to improve the validity and uptake of these standards are discussed. CONCLUSION The European Pain Federation task force present 17 standards of the diagnosis and management of CRPS for use in Europe. These are considered achievable for most countries and aspirational for a minority of countries depending on their healthcare resource and structures. SIGNIFICANCE This position statement summarizes expert opinion on acceptable standards for CRPS care in Europe.

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MUSCULOSKELETAL

Acetabular coverage differs between standing and supine positions: model-based assessment of low-dose biplanar radiographs and comparison with CT

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Abstract

Objectives To evaluate the feasibility of 2D and 3D acetabular coverage assessments based on low-dose biplanar radiographs (BPR) in comparison with CT, and to demonstrate the influence of weight-bearing position (WBP) on anterior and posterior acetabular coverages.

Methods Fifty patients (21 females, 29 males) underwent standing BPR and supine CT of the pelvis. Using dedicated software, BPR-based calculations of anterior and posterior 2D coverages and anterior, posterior, and global 3D coverages were performed in standardized anterior pelvic plane (APP) and WBP. CT-based anterior and posterior 2D coverages and global 3D coverage was calculated in APP and compared with BPR-based data. Statistics included intraclass correlation coefficients (ICC) and Bland-Altman plots.

Results Mean anterior 2D coverage was 21.2% (standard deviation, ± 7.4%) for BPR and 23.8% (± 8.4%) for CT ($p = 0.226$). Mean posterior 2D coverage was 54.2% (± 9.8%) for BPR and 61.7% (± 9.7%) for CT ($p = 0.001$). Mean global 3D coverage was 46.5% (± 3.0%) for BPR and 45.6% (± 3.6%) for CT ($p = 0.215$). The inter-method reliability between CT and BPR and inter-reader reliability for BPR-based measurements were very good for all measurement (all ICC > 0.8). Based on BPR, mean anterior and posterior 3D coverages were 20.5% and 26.0% in WBP and APP, while 25 patients increased anterior and 24 patients increased posterior 3D coverage from APP to WBP with a relative change of coverage of up to 11.9% and 10.0%, respectively.

Conclusions 2D and 3D acetabular coverages can be calculated with very good reliability based on BPR. The impact of standing position on acetabular coverage can be quantified with BPR on an individual basis.

Key Points

- *2D and 3D acetabular coverages can be calculated with very good reliability based on biplanar radiographs in comparison with CT.*
- *The impact of standing position on anterior and posterior acetabular coverages can be quantified with BPR on an individual basis.*

Keywords Acetabulum · Hip joint · Radiography · Weight-bearing · Reproducibility of results

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Abbreviations

2D	Two-dimensional
3D	Three-dimensional
APP	Anterior pelvic plane
BPR	Biplanar radiographs
CT	Computer tomography
FAI	Femoroacetabular impingement
ICC	Intraclass correlation coefficient
WBP	Weight-bearing position

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Introduction

In many patients with hip disorders, the acetabulum has an abnormal size and morphology [1]. Patients with developmental dysplasia of the hip have too little acetabular coverage, while other hip conditions are associated with too much acetabular coverage, most notably pincer-type femoroacetabular impingement (FAI) [2]. In this context, the global acetabular coverage has been defined as the total femoral head area that is covered by the acetabulum [1]. The acetabular coverage can be further divided into an anterior and a posterior portion: This allows a more detailed analysis of the hip joint morphology and has received considerable attention in recent years [3–6]. The pelvic tilt and thus the anterior and posterior acetabular coverages change with the supine and standing positions [7]. With the increasing importance of hip preservation surgery, analysis of the acetabular morphology has become more important for understanding the biomechanics of the hip, for example, in assessing FAI in patients with acetabular retroversion, where the anterior acetabular wall shows a relative prominence, but where the overall area of the lunate surface of the acetabulum may be reduced [8]. As such, acetabular coverage measurements are of special interest for evaluation of patients with suspected global or focal coverage abnormalities of the acetabulum and for planning of hip preservation surgery or periacetabular osteotomy [9].

Acetabular morphology has been evaluated on conventional radiographs for many years, e.g., by assessing the crossover sign, the posterior wall sign, the center-edge angle, or Lequesne's acetabular index [10–12]. The coverage of the femoral head can be assessed on radiographs by calculating the overlap of the anterior and posterior acetabular wall areas with the femoral head, representing the anterior and posterior two-dimensional (2D) acetabular coverages [13] (Fig. 1). However, pelvic tilt and malrotation often substantially affect these 2D assessments, making it difficult to compare between individuals and limiting its clinical applicability [4, 14, 15].

Three-dimensional (3D) acetabular coverage calculations based on computed tomography (CT) can overcome some of these shortcomings by allowing standardization of pelvic orientation along the anterior pelvic plane (APP) [3, 16, 17]. However, due to the supine positioning of patients during cross-sectional imaging, the physiological weight-bearing position (WBP) and natural pelvic tilt cannot be assessed, so these potentially important biomechanical parameters are missed.

Co-registered biplanar radiographs (BPR) are performed on weight-bearing patients and allow calculations of 3D models of the hip joint using dedicated software [18]. Based on those models, anterior and posterior 2D and 3D acetabular coverages can be calculated both in APP and in WBP. This may solve the shortcomings of radiograph- and CT-based

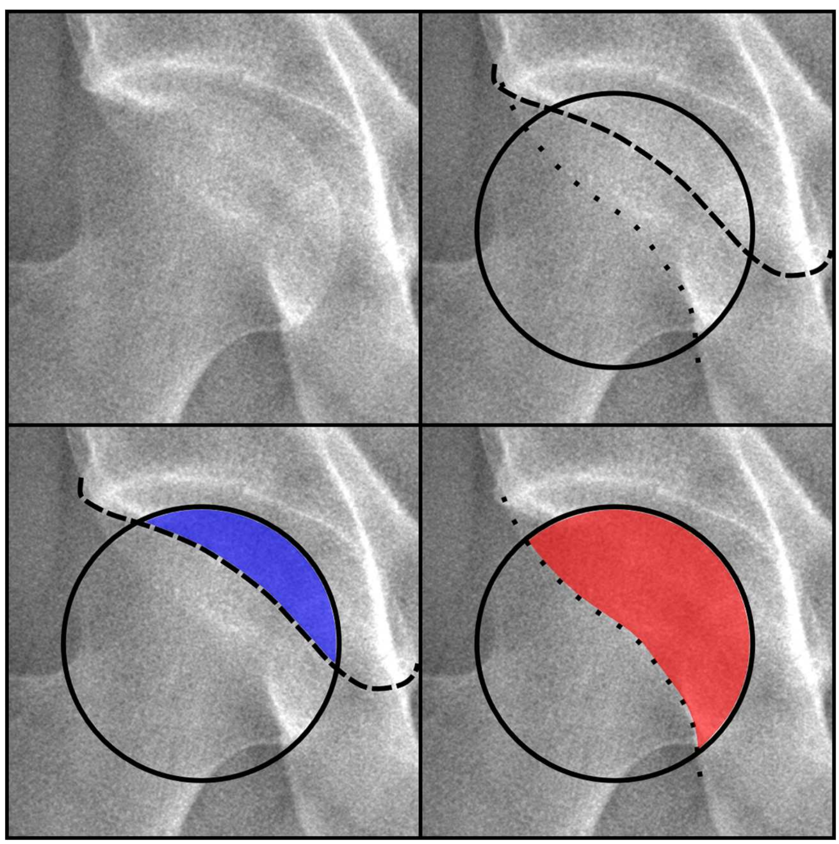


Fig. 1 Anterior and posterior 2D acetabular coverages: anteroposterior image of biplanar radiographs (BPR) of the left hip joint of a 39-year-old male patient. The solid circle represents a best-fit circle adapted to the femoral head. The dashed line represents the contour of the anterior wall of the acetabulum. The dotted line represents the contour of the posterior wall. The blue area on the left lower image represents the anterior 2D acetabular coverage, which was in this patient 18%. The red area on the right lower image represents the posterior 2D acetabular coverage, which was in this patient 44%

acetabular coverage assessments by providing data that is comparable in-between individuals but also reflects the weight-bearing position of the patients. Moreover, there is an additional benefit of a considerably lower radiation dose of BPR compared with CT [19, 20].

The objectives of this study were to evaluate the feasibility of 2D and 3D acetabular coverage assessments based on low-dose BPR in comparison with CT and to demonstrate the influence of weight-bearing on anterior and posterior acetabular coverages.

Material and methods

Patients

This retrospective study was approved by the local ethics committee. A total of 50 consecutive patients, who underwent co-registered biplanar radiographs (BPR) of the pelvis and lower extremities as well as CT of the pelvis, were included into the study with the following inclusion criteria: (i) available BPR, covering the pelvis from the level of the anterior superior iliac spine to below the pubic symphysis; (ii) available CT, covering the pelvis from the level of the anterior superior iliac spine to below the pubic symphysis; (iii) time interval no longer than 6 months between the BPR and the CT; (iv) age of 18 years or older. All patients were referred to our institution for lower extremity imaging by board-certified orthopedic surgeons, in most cases during the course of preoperative evaluation for total knee arthroplasty in patients with osteoarthritis, which routinely consists in our institution of BPR of the pelvis and lower extremities for determination of mechanical leg axes as well as of CT of the pelvis, knee, and ankle for determination of rotational alignment and production of patient-specific surgical cutting blocks and implants.

Study design

The study design is presented in Fig. 2. For all patients, anterior and posterior 2D acetabular coverages and global 3D acetabular coverage were calculated in two separate ways: (1) based on BPR, using dedicated software feasible of translating the co-registered biplanar radiographs semi-automatically into 3D models as well as by using a custom-made software package, which calculates 2D and 3D acetabular coverages based on the generated pelvic and femoral 3D models, as described below in detail; (2) based on CT, using segmentation and analysis software, which served as the standard of reference and for validation of the BPR-based acetabular coverage calculations. For both CT and BPR, acetabular coverages were calculated in the anterior pelvic plane (APP), while additional calculations of acetabular coverages in the weight-bearing position (WBP) were only performed for BPR. All reconstructions and measurements were performed by a fellowship-trained musculoskeletal radiologist (reader 1, 5 years of experience in musculoskeletal radiology).

Imaging parameters

Biplanar radiographs (BPR) were acquired simultaneously on upright patients in natural posture from strict anteroposterior and lateral directions using a dedicated low-dose BPR scanner (EOS imaging system, EOS imaging Inc.) with the following specifications: tube voltage 83–95 kV and tube current 200–280 mA for the anteroposterior image and tube voltage 102–120 kV and tube current 200–320 mA for the lateral image

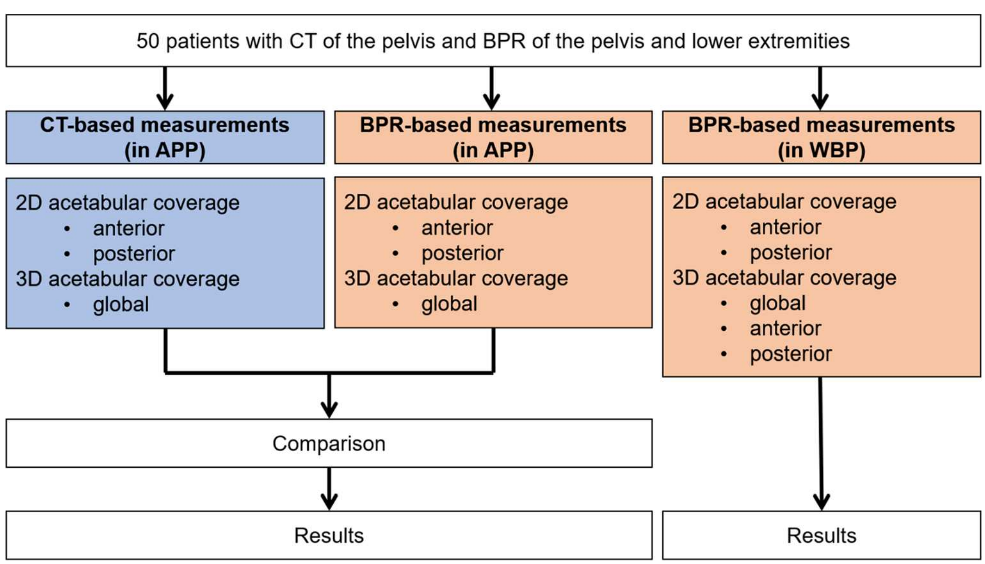


Fig. 2 Flow chart of the study design for acetabular coverage assessment in 50 consecutive patients. CT, computed tomography; BPR, biplanar radiography; APP, anterior pelvic plane; WBP, weight-bearing position

(adapted to patient size). CT examinations were performed on a 64-slice CT scanner (Philips Brilliance 64, Philips Healthcare, or Somatom Definition AS, Siemens Healthcare) using our standard protocol for rotational alignment measurements of the lower extremities, consisting of short scans covering the hip joints, knees, and ankles. Technical specifications for the CT scans were as follows: tube voltage of 120 kV, tube current of 250 mAs, collimation of 64 × 0.625 mm, and rotation time of 0.5 s. Axial images were reconstructed with 1mm slice thickness in bone kernel.

BPR analysis

Using dedicated commercially available semi-automated software (sterEOS software, EOS imaging Inc.), 3D models of the pelvis and both femurs were calculated based on anteroposterior and lateral radiographs, as described in previous studies [18, 21, 22]. The software allows the user to adapt the contours of a predefined model of the pelvis and femur to patient's anatomy on both anteroposterior and lateral radiographs by adjusting several predetermined reference points (Fig. 3). These reference points are placed on critical locations influencing main anatomical characteristics of the pelvis and femur, like the size and shape of the anterior or posterior acetabular wall or the diameter of the femoral head. After careful adjustment of the model contours on anteroposterior and lateral radiographs, the software assesses relationships between the adapted contours to a reference database, calculates anatomical characteristics, and generates 3D models of the femur and pelvis. Based on those models, calculations of the anterior and posterior 2D and 3D acetabular coverages in APP and WBP were achieved fully automated by applying a second software package capable of assessing the relationship of the acetabulum of the pelvic 3D model to the proximal femur of the femoral 3D model (sterEOS software, EOS imaging Inc.). This prototype software package was custom-made and is not yet commercially available. Besides numeric output quantifying anterior and posterior 2D and 3D coverages, this software also provides images of the anterior and posterior 2D overlays of the femoral head and acetabulum. To evaluate inter-reader reliability, the entire reconstructions for acetabular coverage calculations were performed independently on all 50 patients by a second fellowship-trained musculoskeletal radiologist (reader 2, with 7 years' experience in musculoskeletal radiology).

CT analysis and definition of 2D and 3D acetabular coverages

CT models were created using specialized software, capable of segmentation, 3D reconstruction, and measurement of 3D surfaces (Mimics Innovation Suite and 3-matic, Materialise NV). First, segmentation of the hip joint was performed on axial images with a slice thickness of 1 mm with separate definition of the acetabulum and the proximal femur using thresholding techniques. During this process, the fovea capitis was removed and the convexity of the adjacent cortical bone of the femoral head expanded over this area. Afterwards, 3D models of the hip joint were calculated and rotated into the APP, which aligns the most anterior aspects of both anterior superior iliac spines and both pubic tubercles into a coronal vertical plane [23]. This realignment corrects differences of pelvic orientation between supine and weight-bearing examinations, allowing comparisons in-between patients and modalities (Fig. 4).

2D acetabular coverage Transparency of the 3D model of the acetabulum and the femur was increased until the anterior and

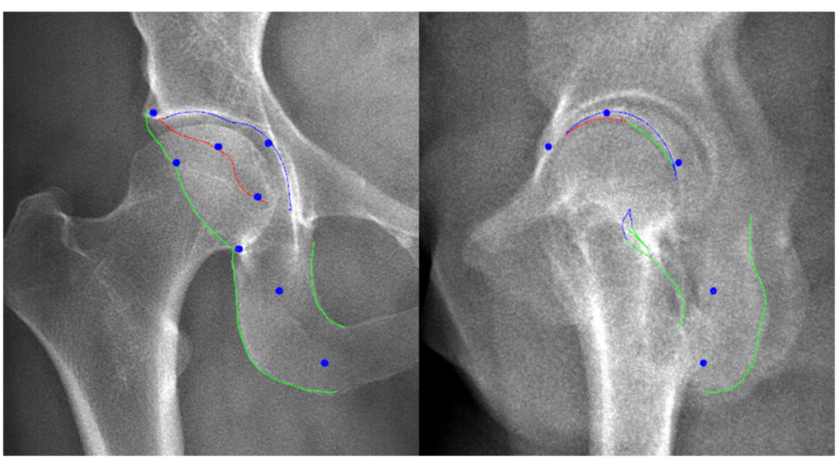


Fig. 3 Anteroposterior and lateral images of the biplanar radiographs (BPR) of the right hip joint in a 45-year-old male patient. The blue points represent critical landmarks that can be adjusted manually to influence the contours of the acetabulum and pelvis until the model fits onto the radiographs. The red line represents the contour of the anterior acetabular wall, the blue line the acetabular fossa, and the green lines the posterior acetabular wall and the inferior pubic ramus

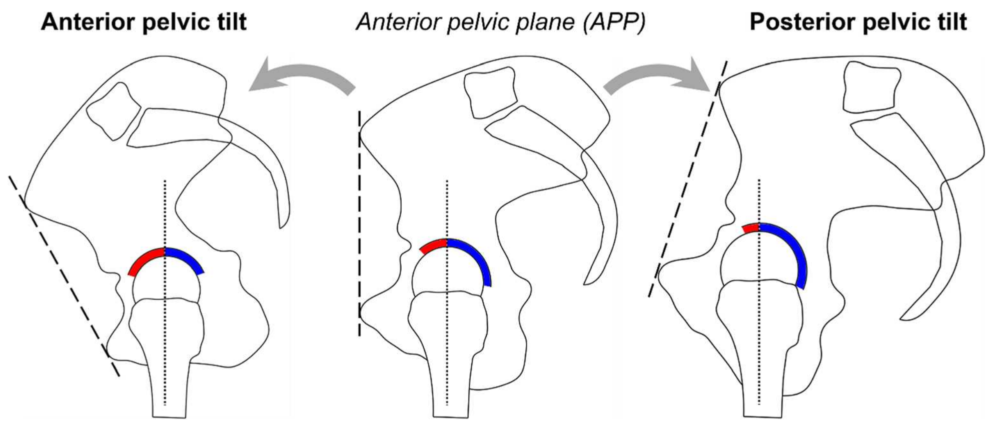
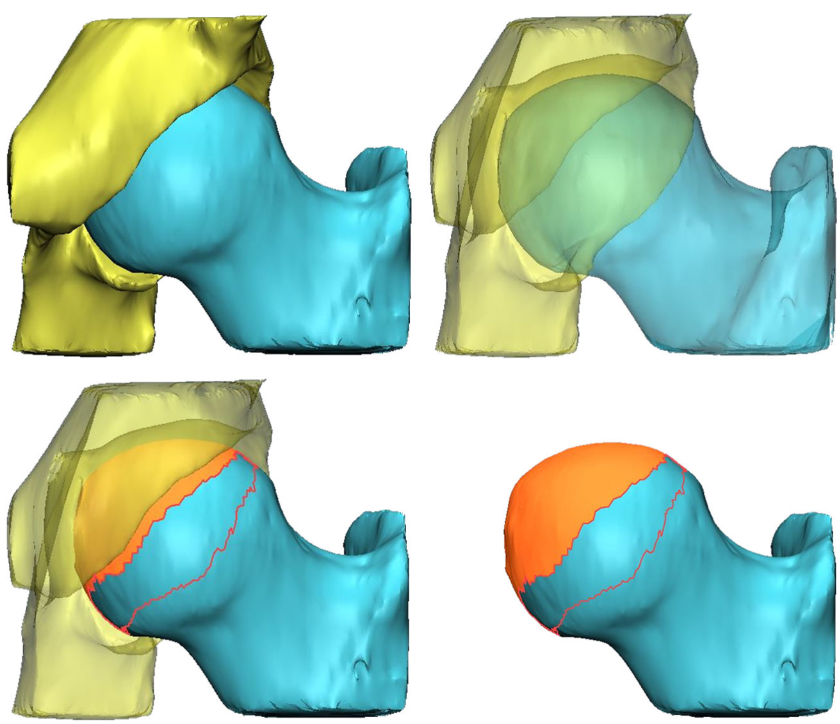


Fig. 4 Schematic drawing of a lateral view of the pelvis illustrating the association of pelvic tilt and anterior and posterior acetabular coverages. The dashed line represents the anterior pelvic plane (APP), which touches both anterior superior iliac spines and the pubic symphysis. In the middle image, the APP is aligned to the vertical axis. The dotted line represents a vertical plane crossing both femoral head centers. The red curved line represents the anterior acetabular coverage and the blue curved line represents the posterior acetabular coverage. Note the influence of anterior and posterior tilts on anterior and posterior acetabular coverages in comparison with neutral position (middle image). In our study, 25 patients demonstrated anterior pelvic tilt while 24 patients demonstrated posterior pelvic tilt in weight-bearing position in comparison with the neutral position (vertical anterior pelvic plane)

posterior walls of the acetabulum as well as the entire femoral head were clearly determinable. This image was transferred to an open-source image processing package capable of measuring areas (Fiji, http://imagej.net/Fiji [24]). A best-fit circle was adapted to the femoral head and considered to represent the 2D femoral head area. In addition, the intersected area of the femoral head with the anterior as well with the posterior acetabular wall was measured. The anterior or posterior 2D coverage is the ratio of the corresponding intersected acetabular wall area and the femoral head area in percent (Fig. 1).

Global 3D acetabular coverage Global 3D coverage of the acetabulum was defined as the ratio of the area of the femoral head surface covered by the acetabulum and the surface of the entire femoral head, approximated by a best-fit sphere adapted to the femoral head. To define the femoral head area covered by the acetabulum, we constructed a spline along the rim of the acetabulum and projected it onto the femoral head surface, directed towards the femoral head center (Fig. 5). The center of the femoral head was defined to be the center of a best-fit sphere constructed for approximation of the entire femoral

Fig. 5 3D acetabular coverage: anterior views of a 3D reconstruction of the left hip joint based on computed tomography (CT) of a 67-year-old male patient. The acetabulum is presented in yellow and the proximal femur in light blue. The 3D area of the femoral head covered by the acetabulum (global 3D acetabular coverage) is demonstrated by the orange line and was 50.8% in this patient, and the orange area is the anterior portion of the 3D acetabular coverage



head surface. The femoral head area covered by the acetabulum was measured and divided by the entire femoral head area, which was approximated by the surface of a best-fit sphere.

Statistics

Statistical analysis was performed using SPSS version 21.0 (IBM Corp.) and MedCalc version 17.6 (MedCalc Software bvba). General descriptive statistics were applied with continuous data being reported as means and standard deviations and categorical data as proportions. The Mann-Whitney *U* test was applied to test for statistically significant differences of patient age and of acetabular coverage values between CT and BPR and between APP and WBP. A p value of < 0.05 was considered to represent statistical significance. Bland-Altman plots were used to compare coverage calculations based on BPR and CT [25]. The two-way random effects intraclass correlation coefficient (ICC) was applied to measure inter-method and inter-reader reliability. ICC values of > 0.75 were considered to represent very good agreement [26].

Results

The 50 included patients had a mean age of 69.7 years (standard deviation [SD], 8.8 years; range, 53–87 years) and consisted of 29 men with a mean age of 70.2 years (SD, 9.2 years; range, 53–87 years) and 21 women with a mean age of 69.1 years (SD, 8.5 years; range, 54–83 years). Age was not significantly different between male and female patients ($p = 0.672$). For each patient, acetabular coverage was evaluated on only one hip joint. The left hip joint was examined in 44% of patients (22/50) and the right hip joint was examined in 56% of patients (28/50).

Coverage comparison between CT and BPR

The values for 2D and 3D coverages aligned to the anterior pelvic plane (APP) for CT and BPR are presented in Table 1. The mean difference between CT and BPR was 0.9% for global 3D coverage ($p = 0.215$), 2.6% for anterior 2D coverage ($p = 0.0226$), and 7.5% for posterior 2D coverage ($p = 0.001$). Inter-method reliabilities were very good for all measurements. Figure 6 shows the corresponding Bland-Altman plots. The range between the two limits was for anterior 2D acetabular coverage 23.8%, for posterior 2D acetabular coverage 26.3%, and for global 3D coverage 9.3%. The variability of results was random for all three Bland-Altman plots.

Coverage comparison between APP and WBP based on BPR

The coverages for BPR-based calculations based on APP and WBP are presented in Table 2. In WBP, absolute coverage values showed mean differences of up to 1.3% compared with APP, without significant differences for all measurements (all $p > 0.4$). The range of relative change was for 2D coverage calculations higher (ranging from − 49.5 to 78.9%), compared with 3D calculations (ranging from − 11.9 to 11.4%).

When compared with the APP, 25 patients demonstrated anterior pelvic tilt while 24 patients demonstrated posterior pelvic tilt in WBP: This means that during the transformation from APP to WBP, 25 patients increased anterior coverage and 24 patients increased posterior coverage. For one patient, anterior and posterior coverages were the same on APP and WBP.

The inter-reader reliability for BPR-based measurements in APP and WBP was very good for all calculations (Table 3).

Discussion

Our study demonstrates the feasibility of 2D and 3D acetabular coverage calculations based on biplanar radiographic (BPR) data. For both anterior 2D and global 3D coverage calculations, differences between BPR- and CT-based calculations were small and inside clinically acceptable limits. Significant differences existed for posterior 2D coverage calculations, but the overall inter-method reliabilities between CT and BPR were very good with ICC values ≥ 0.8 for all assessments. BPR offer the unique capability of analyzing 2D

Table 1 Acetabular coverage in the anterior pelvic plane (APP): comparison of CT- and BPR-based data

	CT (SD) [range]	BPR (SD) [range]	*p* value	Difference between CT and BPR	ICC
Anterior 2D coverage	23.8% (± 8.4%) [6.5–42.8%]	21.2% (± 7.4%) [3.7–38.3%]	0.226	2.6%	0.830 (0.695–0.905)
Posterior 2D coverage	61.7% (± 9.7%) [45.9–81.6%]	54.2% (± 9.8%) [37.3–81.1%]	0.001	− 7.5%	0.864 (0.756–0.924)
Global 3D coverage	45.6% (± 3.6%) [38.7–55.5%]	46.5% (± 3.0%) [41.3–53.3%]	0.215	0.9%	0.842 (0.717–0.912)

Percentages indicate the proportion of the femoral head covered by the acetabulum. Coverages are calculated after aligning the pelvis to the anterior pelvic plane. *p* values compare the coverage assessments of CT and BPR. *CT*, computed tomography; *BPR*, biplanar radiography; *ICC*, intraclass correlation coefficient; *SD*, standard deviation

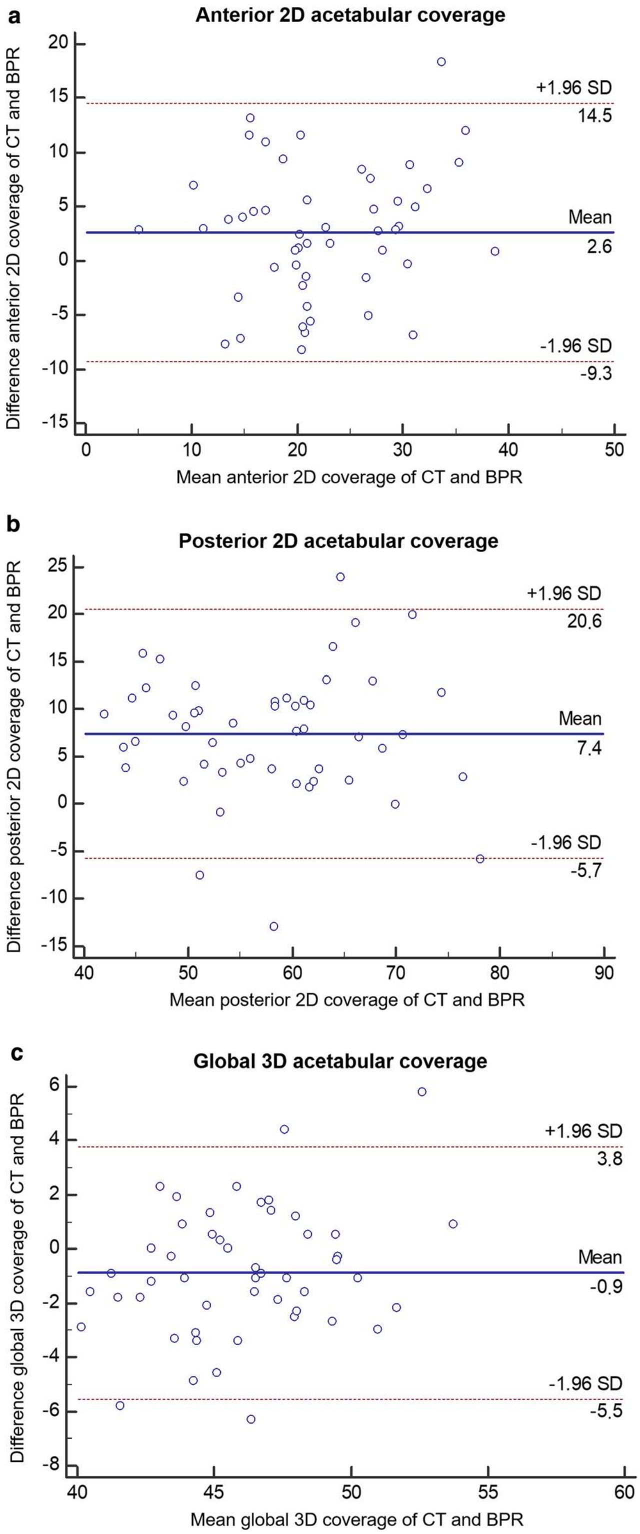


Fig. 6 Bland-Altman plots for anterior 2D acetabular coverage, posterior 2D acetabular coverage, and global 3D acetabular coverage. The upper limit, lower limit, and mean value was 14.5%, −9.3%, and 2.6% for anterior 2D acetabular coverage; 20.6%, −5.7%, and 7.4% for posterior 2D acetabular coverage; and 3.8%, −5.5%, and −0.9% for global 3D acetabular coverage assessments, respectively. CT, computed tomography; BPR, biplanar radiograph; SD, standard deviation

and 3D coverages in WBP and hereby demonstrate the impact of pelvic tilt on acetabular coverage values.

The BPR-based acetabular coverage calculations presented in this study combine benefits of weight-bearing radiograph-based and supine CT-based coverage calculations. Inter-method reliabilities between BPR and CT were very good. Most notably, the difference between global 3D acetabular coverage assessments for CT and BPR was only 0.9% and well below the standard deviations of 3.6% and 3.0%, respectively. However, some limitations exist for BPR-based posterior 2D acetabular coverage calculations, which were significantly lower compared with CT-based calculations by 7.5%. However, considering the relatively high standard deviations of 9.8% and 9.7% of both methods and the very good ICC of 0.867, the difference between BPR-based and CT-based posterior 2D coverage assessments may not be clinically relevant.

Up to now, anterior and posterior 3D coverage calculations were not obtainable by using either standard supine cross-sectional imaging or conventional radiographs. Recently, upright weight-bearing cone beam scanners became commercially available, which may also provide 3D coverage analyses on WBP, however at cost of a high radiation dose. In contrast, BPR affords examinations with very little radiation dose, even lower than standard conventional radiographs [19, 20]. This is particularly relevant because hip morphology and acetabular coverage analyses are especially important for adolescent and young adult patients, as abnormalities like developmental dysplasia of the hip or FAI are usually assessed in these age groups [27–30].

Only sparse literature is available on 3D acetabular coverage assessment techniques. In our study, we performed CT-based measurements of the area of the femoral head surface covered by the acetabulum and calculated the ratio to the full surface of the femoral head, which was approximated by a sphere. Even though other published techniques use similar approaches, like the approximation of the femoral head surface by a sphere, methodological differences exist for evaluation of the area of the covered femoral head surface. Dandachli et al used 3D reconstructions to project the superior half of the acetabulum onto the femoral head and subsequently projected these structures on a two-dimensional plane, creating a two-dimensional image of acetabular coverage [16]. Hansen et al projected the acetabular rim to the nearest point of the femoral head surface, which however was not approximated by a sphere, but measured from the most superior part of the femoral head to the head-neck junction [31]. Most similarities of our study in terms of comparability of acetabular coverage calculations exist with a study by Larson et al, which measured local acetabular coverages on radial reformatted slices along the horizontal plane, but also projected the acetabular rim on the femoral head, which was also approximated by a best-fit sphere [3]. Global 3D acetabular coverage values of this study were 40% (± 2%), thus being 6% lower than CT-based values of our study. These

Table 2 Acetabular coverage for measurements based on BPR: comparison between anterior pelvic plane (APP) and weight-bearing position (WBP)

BPR	APP	WBP	Mean change between APP and WBP	Range of absolute change from APP to WBP	Range of relative change from APP to WBP
2D acetabular coverage					
Anterior	21.2% (± 7.4%) [3.7–38.3%]	20.0% (± 7.5%) [3.1–32.3%]	1.2% (± 4.1%)	− 8.7 to 9.0%	− 49.5 to 78.9%
Posterior	54.2% (± 9.8%) [37.3–81.1%]	55.5% (± 9.4%) [36.5–76.1%]	− 1.3% (± 4.7%)	− 7.1 to 12.6%	− 34.4 to 31.6%
3D acetabular coverage					
Global	46.5% (± 3.0%) [41.3–53.3%]	46.5% (± 3.0%) [41.2–53.3%]	0.0% (± 0.1%)	− 0.1 to 0.1%	
Anterior	20.5% (± 2.4%) [14.9–25.1%]	20.5% (± 2.2%) [16.2–24.4%]	0.0% (± 1.1%)	− 2.5 to 2.5%	− 11.9 to 11.4%
Posterior	26.0% (± 2.3%) [21.4–30.9%]	26.0% (± 2.1%) [21.5–30.2%]	0.0% (± 1.1%)	− 2.5 to 2.5%	− 8.4 to 10.0%

Values in parentheses represent standard deviations. Values in brackets represent ranges. For change average and change range, negative values denote decreases of coverage values on WBP in comparison with APP. *BPR*, biplanar radiography; *APP*, anterior pelvic plane; *WBP*, weight-bearing position

differences might be partially explained by subtle differences in the 3D acetabular coverage assessment technique, but also in differences of the study populations, since Larson et al measured healthy individuals with a mean age of 25 years, while our study population was not asymptomatic regarding the hip joint with a considerably higher mean age of 70 years.

Due to the unique capability of BPR-based acetabular coverage assessments in APP and WBP, we were able to demonstrate the effect of pelvic tilt on acetabular coverage values. It sticks out that the mean values of anterior and posterior 3D acetabular coverages were nearly identical between APP and WBP, which we believe is a coincidence of the study population, since half the patients showed an anterior and about half the patients showed a posterior pelvic tilt from APP to BPR. However, some patients showed an absolute increase of up to 2.5% for anterior and of up to 2.5% for posterior 3D acetabular coverage. Even though these numbers may seem relatively small, they still comprise for more than one standard deviation of the absolute coverage values of our study population. When putting the individual differences of anterior and posterior 3D coverages between APP and WBP into relation to the absolute coverage values, we found a relative individual change of up to 11.9% for anterior and 10% for posterior 3D coverage. Up to now, we do not know if these differences of 3D anterior and posterior coverage values are of clinical relevance, since appropriate studies are missing.

Table 3 Inter-reader reliability for BPR-based coverage calculations in anterior pelvic plane (APP) and weight-bearing position (WBP)

	APP	WBP
2D anterior coverage	0.86 (0.7; 0.94)	0.84 (0.66; 0.93)
2D posterior coverage	0.84 (0.67; 0.93)	0.82 (0.68; 0.9)
3D global coverage	0.89 (0.8; 0.94)	0.89 (0.8; 0.94)
3D anterior coverage	0.85 (0.71; 0.92)	0.83 (0.65; 0.92)
3D posterior coverage	0.82 (0.64; 0.91)	0.81 (0.63; 0.9)

Reliability between both readers represented by the intraclass correlation coefficient for biplanar radiography–based coverage calculations in anterior pelvic plane (APP) and weight-bearing position (WBP). Values in parentheses represent the upper and lower ends of the 95% confidence interval

However, this study was supposed to demonstrate the feasibility of the technique. Therefore, we did not examine patients with specific hip disorders but a compilation of clinical patients, which were referred to our institution and imaged for various reasons. Differences of anterior and posterior coverages between APP and WBP are supposedly higher for certain hip disorders, like in patients with symptomatic FAI, which demonstrate increased anterior pelvic tilt as shown by recent studies [5, 32]. Further evaluations with dedicated patient populations should be carried out to precisely assess the range of 3D acetabular coverage changes between APP and WBP in specific hip disorders, like developmental dysplasia of the hip or FAI.

This study has the limitation, that we approximated the shape of the femoral head to be a perfect sphere. We assume that this has only minor influence on coverage results in patients with a normal femoral head. However, this technique may not be applicable in patients with a substantially aspherical femoral head, like patients with Perthes disease or severe osteoarthritis of the hip.

In conclusion, 2D and 3D acetabular coverages can be calculated with very good reliability based on BPR. The impact of standing position on acetabular coverage can be quantified with BPR on an individual basis.

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Compliance with ethical standards

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Conflict of interest The authors of this manuscript declare relationships with the following company: EOS imaging Inc.

Statistics and biometry One of the authors has significant statistical expertise.

No complex statistical methods were necessary for this paper.

Informed consent Written informed consent was waived by the local ethics committee.

Ethical approval Local ethics committee approval was obtained.

Methodology
• retrospective
• diagnostic or prognostic study
• performed at one institution

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